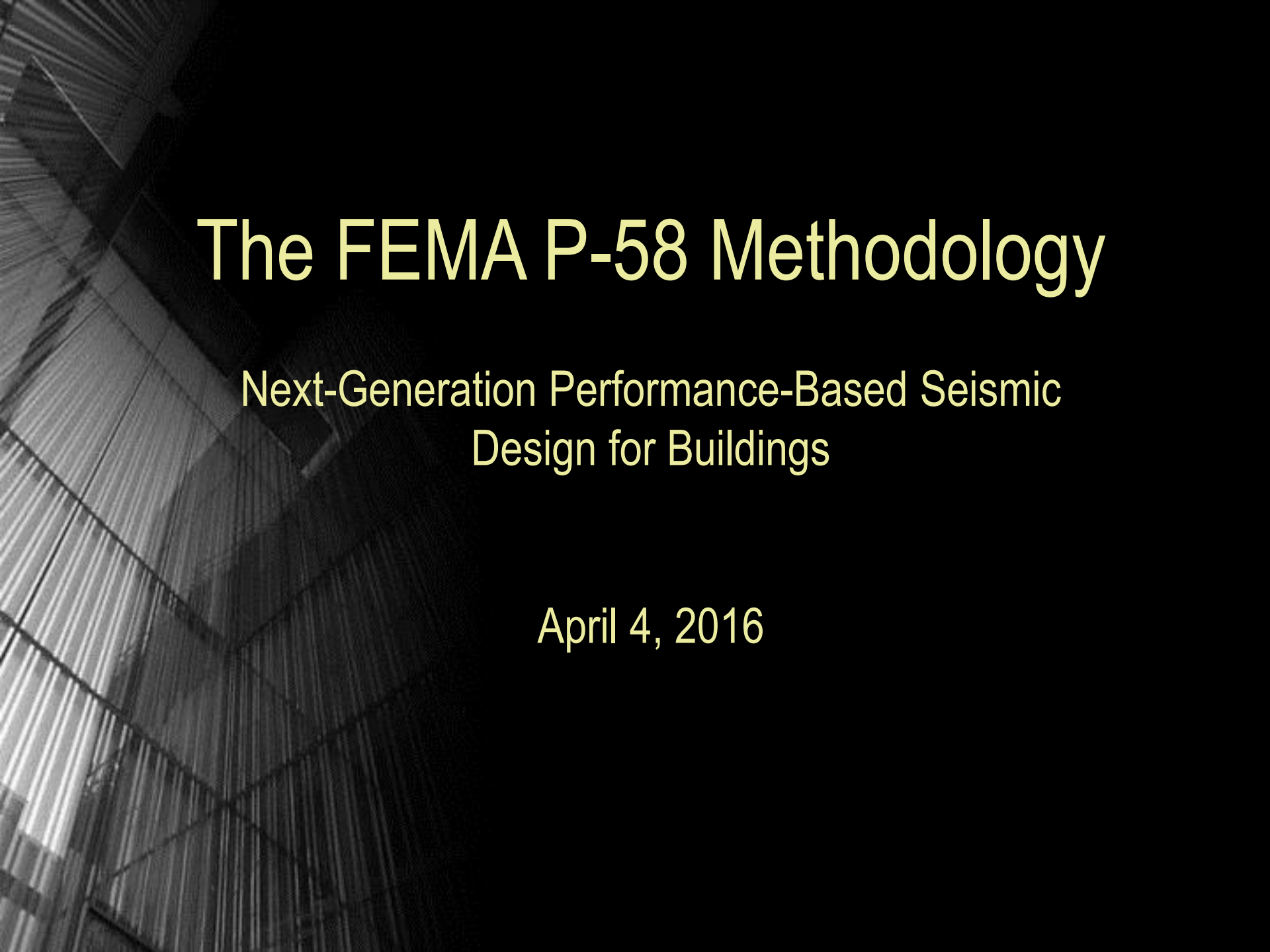


The FEMA P-58 Methodology

Next-Generation Performance-Based Seismic Design for Buildings

April 4, 2016

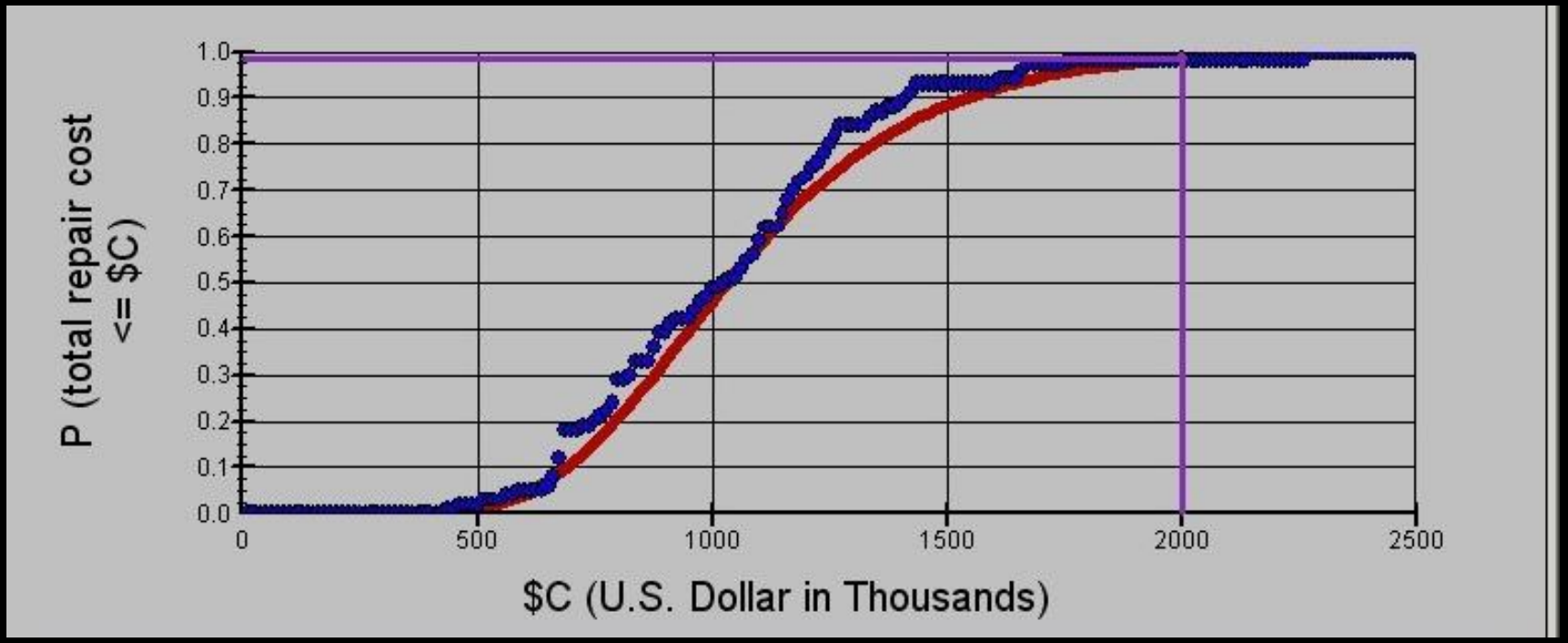
FEMA P-58

- A methodology and supporting tools to assess building seismic performance in terms of the probable consequences of building response to earthquakes, including:
  - Casualties (deaths & serious injuries)
  - Direct economic loss (repair and replacement costs)
  - Indirect economic and social loss (red tags and repair time)
  - Energy and Carbon consequences of poor performance (currently under development)

Assessment Types

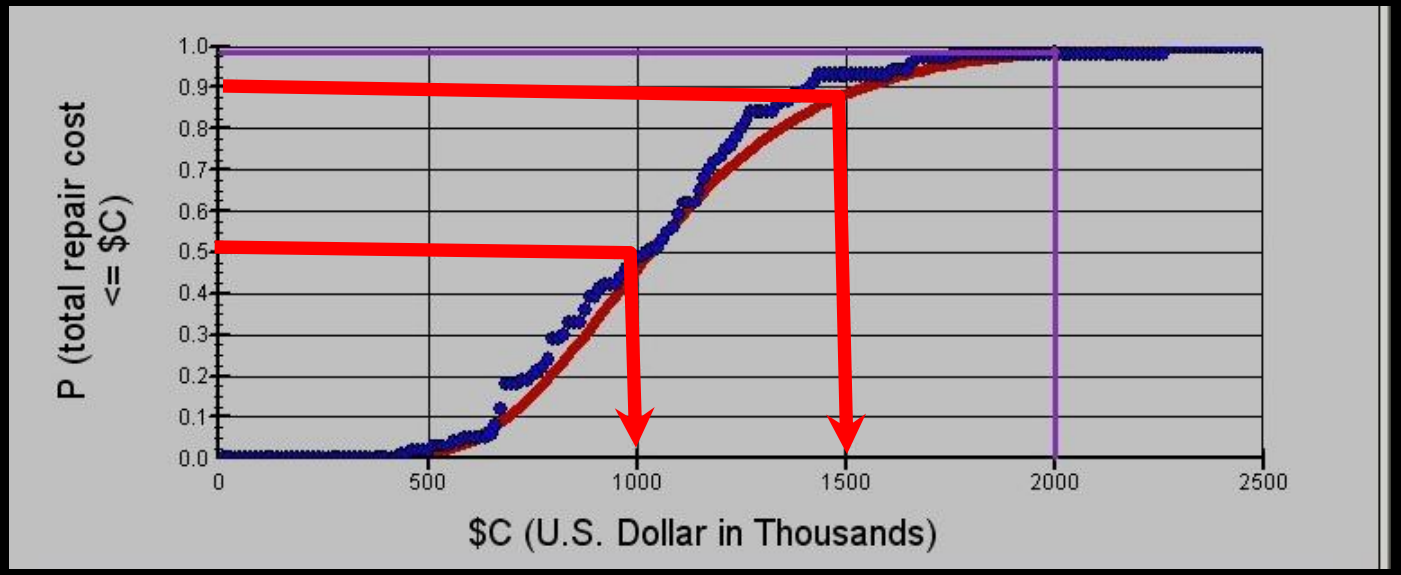
- **Intensity-based**
  - Performance given a specific acceleration response spectrum
- **Scenario-based**
  - Performance given a specific earthquake scenario, e.g. repeat of 1811-1812 New Madrid events
- **Time-based**
  - Performance over a period of time, considering all possible earthquakes, and their individual probabilities of occurrence

FEMA P-58 Performance Results



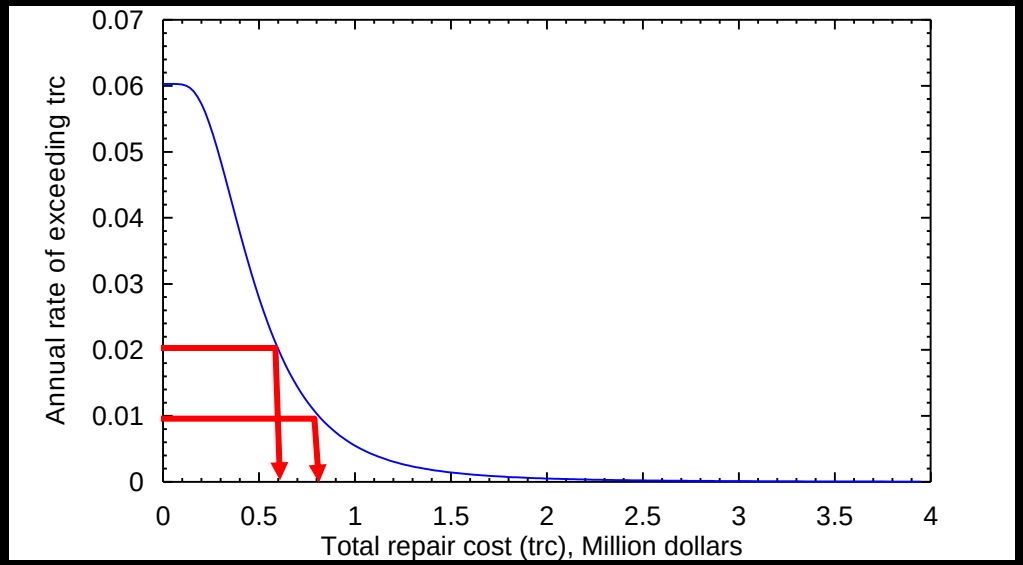
Loss Distribution

Intensity- and Scenario-Based Assessments



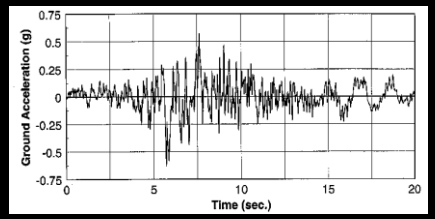
- 50% probability that repair cost (for the scenario or intensity) will not exceed $1M, 1 month repair, 1 injury
- 90% confidence that repair cost (for the scenario or intensity) will not exceed $1.5M, 1.5 month repair, 3 injuries, 1 death
- Expected loss (for scenario or intensity) of $1.2M

Time-based Assessments

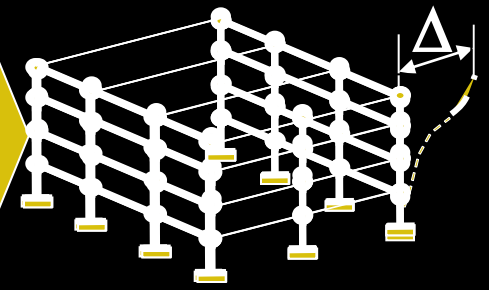


- 50-year loss = $600,000
- 100-year loss = $800,000
- Average annual loss = $66,000

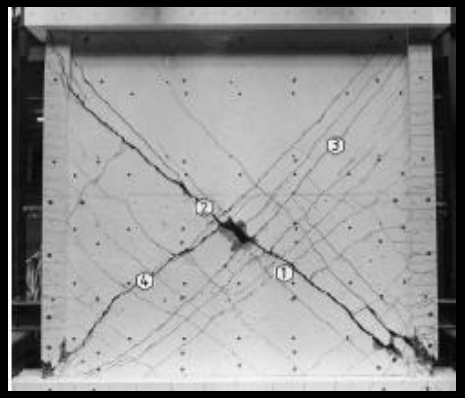
The Process



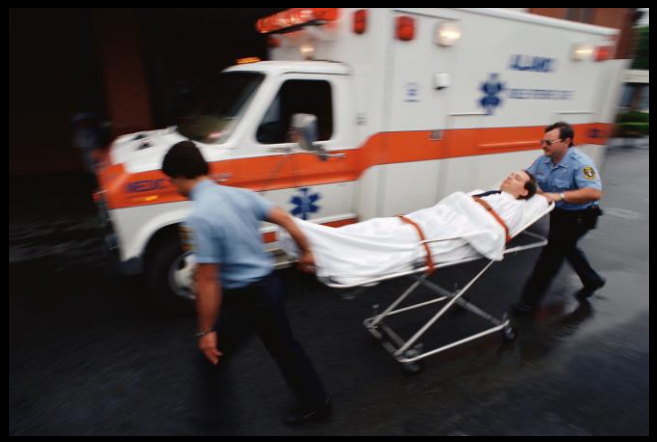
Ground Motion



Structural Response



Damage



Step 1 – Building Performance Model

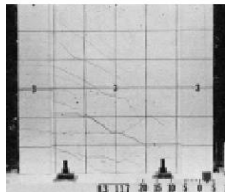
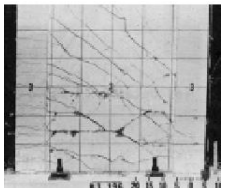
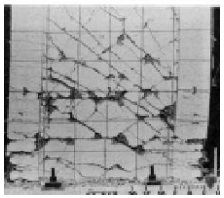
- **Methodical building description**
  - **Site characteristics**
  - **Structural system & details**
    - Damage states, fragility relationships, and consequences of damage
  - **Nonstructural components & systems**
    - Damage states, fragility relationships, and consequences of damage
  - **Occupancy**
    - People at risk, locations, time of day

Building Performance Model

Fragility Specification

Fragility Specification

B1044.000 Reinforced Concrete Shearwalls

BASIC COMPOSITION	Reinforced concrete and finishes both sides		
Units for basic quantities	Square feet of wall area		
DAMAGES STATES, FRAGILIITES, AND CONSEQUENCE FUNCTIONS			
	DS1	**DS2**	**DS3**
DESCRIPTION	Flexural cracks < 3/16" Shear (diagonal) cracks < 1/16"	Flexural cracks > 1/4" Shear (diagonal) cracks > 1/8"	Max. crack widths >3/8" Significant spalling/ loose cover
ILLUSTRATION (example photo or drawing)			
MEDIAN DEMAND	1.5%	3.0%	5.0%
BETA	0.2	0.3	0.4
CORRELATION (%)	70%		
DAMAGE FUNCTIONS	Patch cracks each side with caulk Paint each side	Remove loose concrete Patch spalls with NS grout Patch cracks each side with caulk Paint each side	Shore Demo existing wall Replace Patch and paint
CONSEQUENCE FUNCTION			
Max. consequence up to lower quantity	$4.00 per sq ft up to 800 sq ft	$10.00 per sq ft up to 800 sq ft	$50.00 per sq ft up to 200 sq ft
Min consequence over upper quantity	$2.00 per sq ft over 4000 sq ft	$5.00 per sq ft over to 4000 sq ft	$30.00 per sq ft over 2000 sq ft
Beta (consequence)	0.2	0.3	0.3
TIMEFRAME TO ADDRESS CONSEQUENCES	days	weeks	months

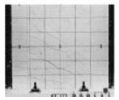
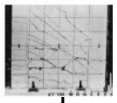
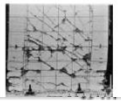
Fragility Specification

Fragility Specification

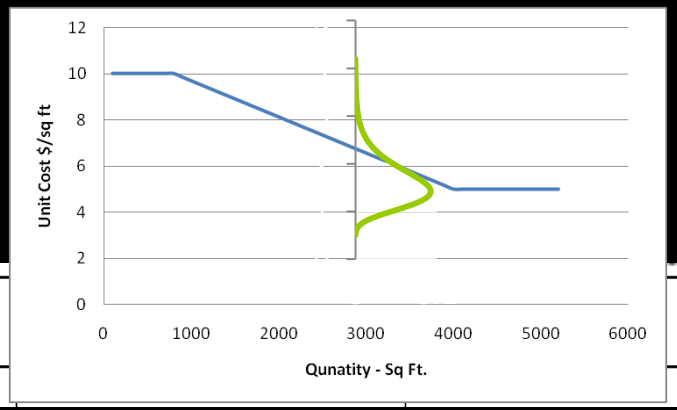
B1044.000 Reinforced Concrete Shearwalls

BASIC COMPOSITION	Reinforced concrete and finishes both sides
Units for basic quantities	Square feet of wall area

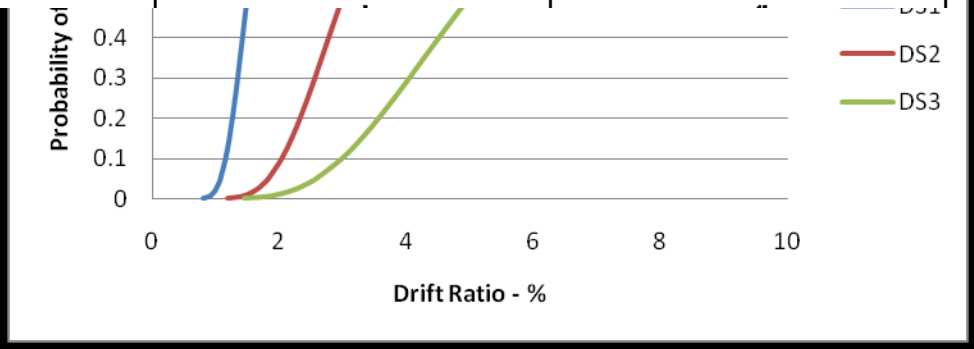
DAMAGES STATES, FRAGILITES, AND CONSEQUENCE FUNCTIONS

	DS1	DS2	DS3
DESCRIPTION	Flexural cracks < 3/16" Shear (diagonal) cracks < 1/16"	Flexural cracks > 1/4" Shear (diagonal) cracks > 1/8"	Max. crack widths >3/8" Significant spalling/ loose cover
ILLUSTRATION (example photo or drawing)			
		Patch cracks each side with caulk Paint each side	Patch and paint

MEDIAN DEMAND	1.5%
BETA	0.2



CONSEQUENCE FUNCTION			
Max. consequence up to lower quantity	$4.00 per sq ft up to 800 sq ft	$10.00 per sq ft up to 800 sq ft	$50.00 per sq ft up to 200 sq ft
Min consequence over upper quantity	$2.00 per sq ft over 4000 sq ft	$5.00 per sq ft over to 4000 sq ft	$30.00 per sq ft over 2000 sq ft
Beta (consequence)	0.2	0.3	0.3



Fragility Specification

Fragility, damage measures, and consequence functions for

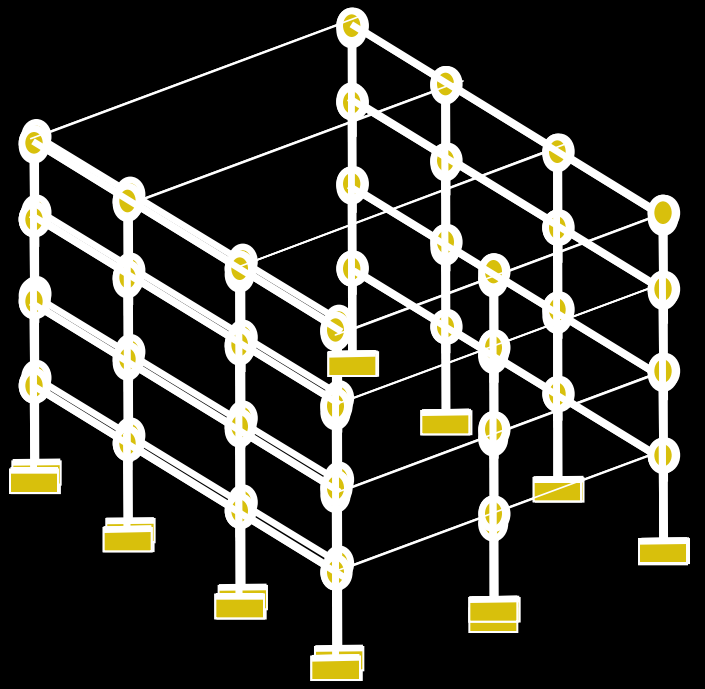
Interior Partitions Type 9a C1011.009a

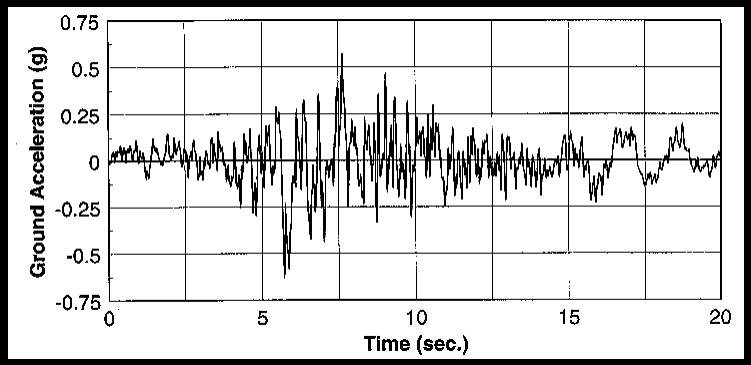
BASIC COMPOSITION	Full height 5/8 inch gypsumboard screwed on metal studs. No slip track or window panels.
NORMATIVE QUANTITIES	Linear feet of partition wall oriented in a specified *direction* per square foot of floor area at a specified level. This quantity will be multiplied by story height to obtain square feet of partition wall.

DAMAGES STATES, FRAGILIITES, AND CONSEQUENCE FUNCTIONS

	DS1	DS2	DS3
DESCRIPTION	Visible damage and small cracks in gypsum boards that can be repaired with taping, pasting and painting. No window and door damage	Extensive cracking or crushing in gypsum boards and minimal or no damage to metal studs. Re-hang door.	Severe damage to gypsum boards and enough damage to metal studs and runners
ILLUSTRATION (example photo or drawing)			
MEDIAN EDP (interstory drift in specified direction)	0.20%	0.80%	1.40%
BETA	0.40	0.40	0.40
CORRELATION (%)	low	low	low
REPAIR MEASURES	Taping ,patching and painting	Replacing the gypsum boards, and then taping, and painting Re-hang doors	Remove damaged materials Reframe walls Repair damaged electrical Install new Gyp Tape, Sand and Paint Includes some door repairs Includes some minor mechanical repairs
CONSEQUENCE FUNCTION Cost per sq ft of interior partition			
Max. cost up to lower quantity	$ 3.33 / 100	$ 5.56 / 100	12.92 / 100
Min cost over upper quantity	$ 2.94 / 10,000	$ 4.76 / 10,000	$ 10.92 / 10,000
Beta (cost)	0.20	0.30	0.30
TIMEFRAME FOR REPAIRS	Minor repairs can be done in a couple of days, including repainting patches	Larger repairs take min. 5 days to remove damage, patch and paint	Major reframing of walls and mechanical damge repairs will take a minimum of 10 days, and possible longer depending on crew size, amount ot damage, and availability of mechanical parts for repairs

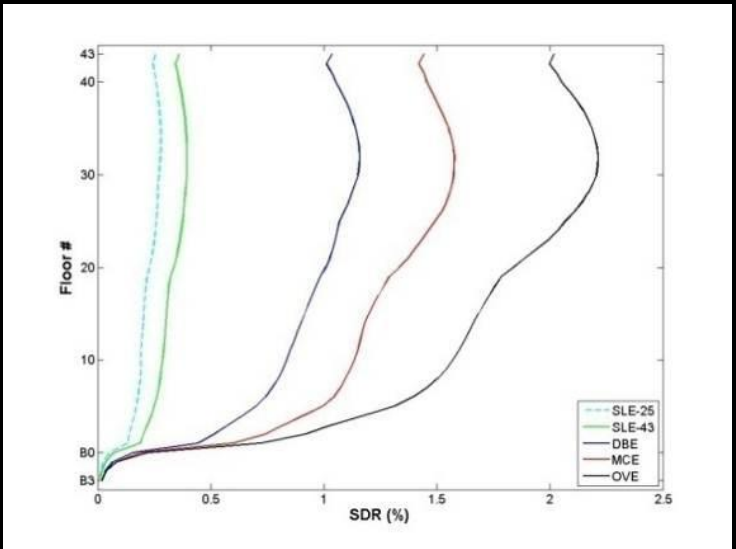
Step 2 – Structural Analysis

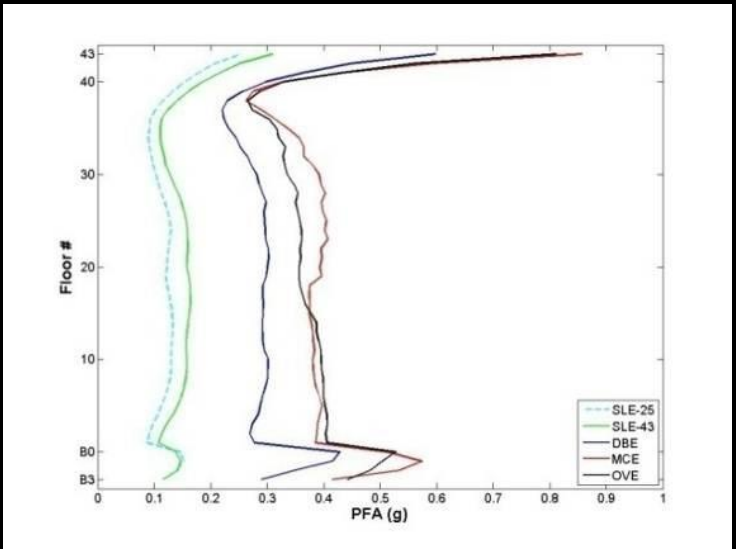




Peak Ground Acceleration	Drift Ratio
0.2g	1.0%
0.5g	2%
1.0g	5%

Analysis Results

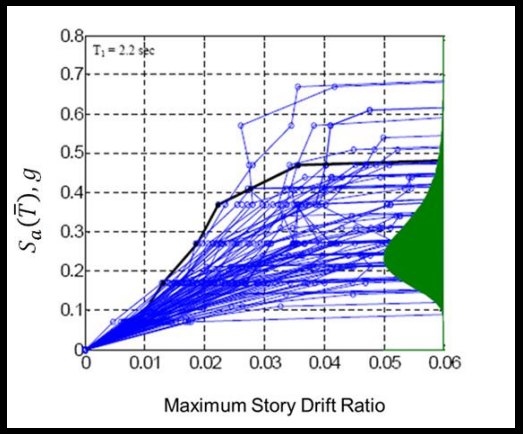


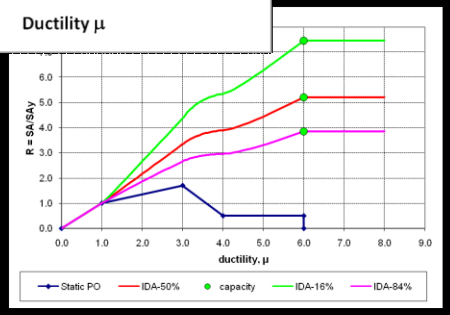


- Median values of peak transient:
  - Story drift
  - Floor acceleration
  - Floor velocity

Step 3 – Collapse Fragility Development

- IDA approach similar to ATC-63
- Pushover analysis (similar to ASCE 41) & SPO2IDA tool
- Judgment-based

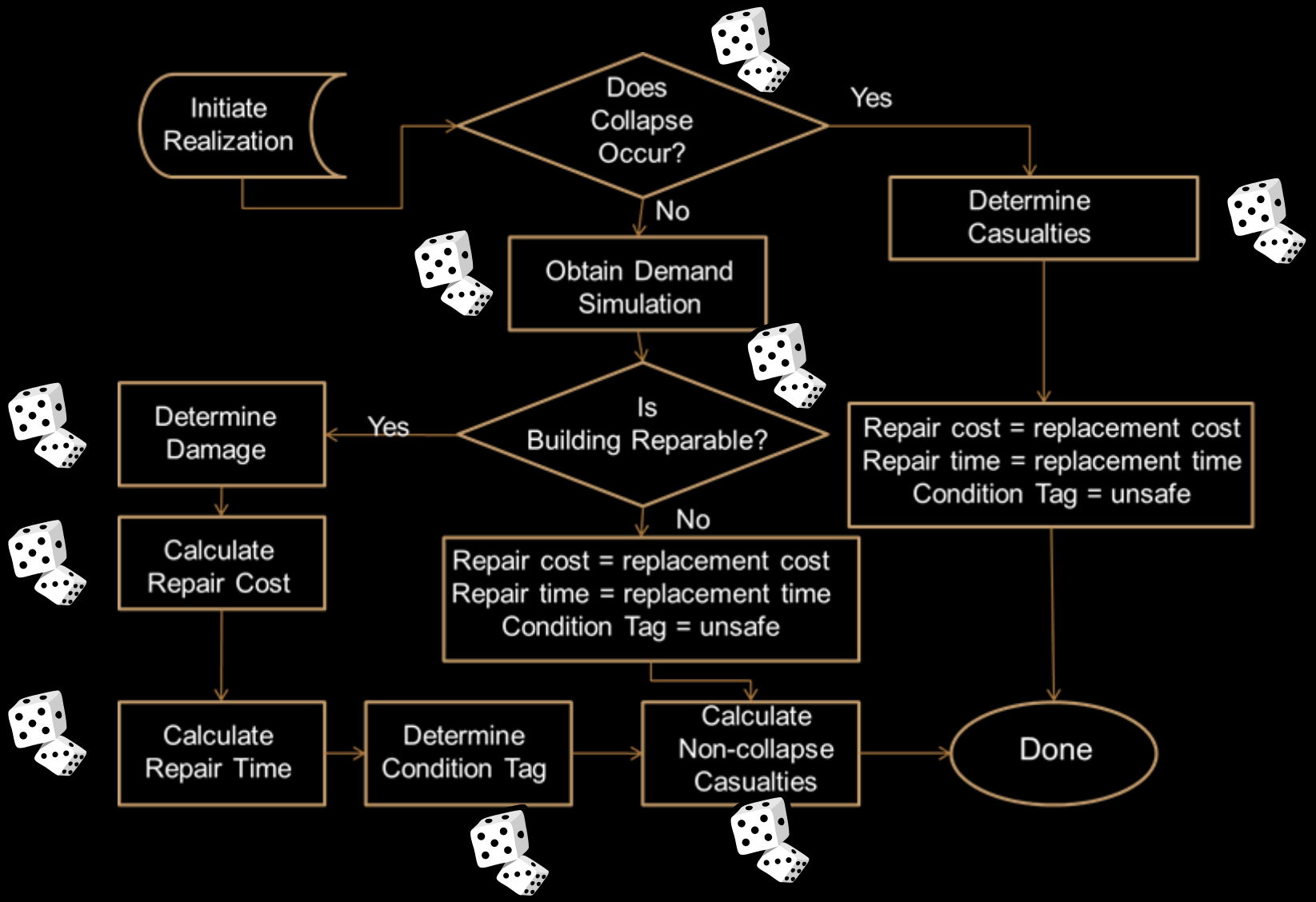




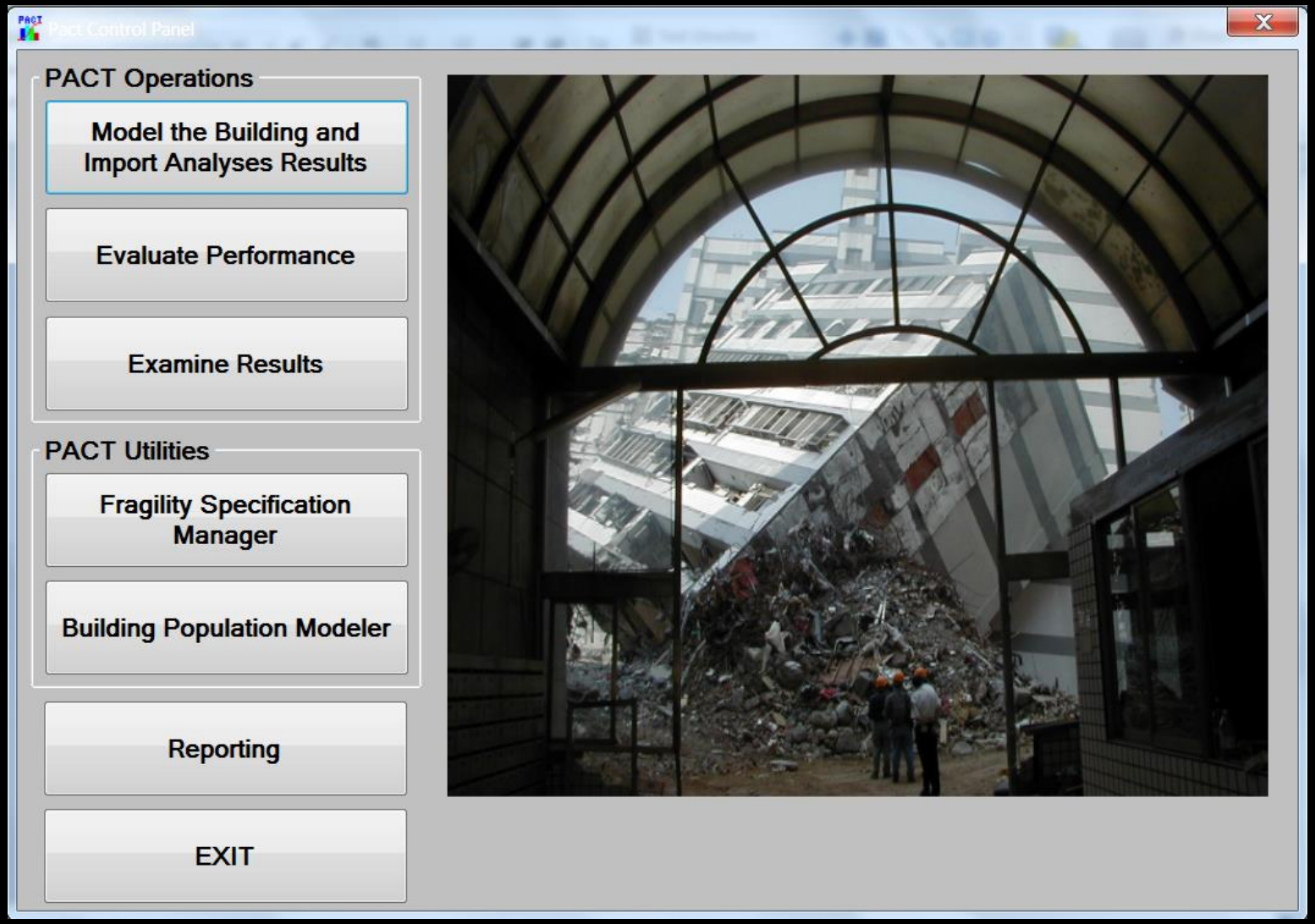
Step 4 – Calculate Performance

- Monte Carlo Process
- Hundreds to thousands of "spins"
- For each "spin" termed a "realization"
- Unique
  - Demands
  - Damage
  - Consequences

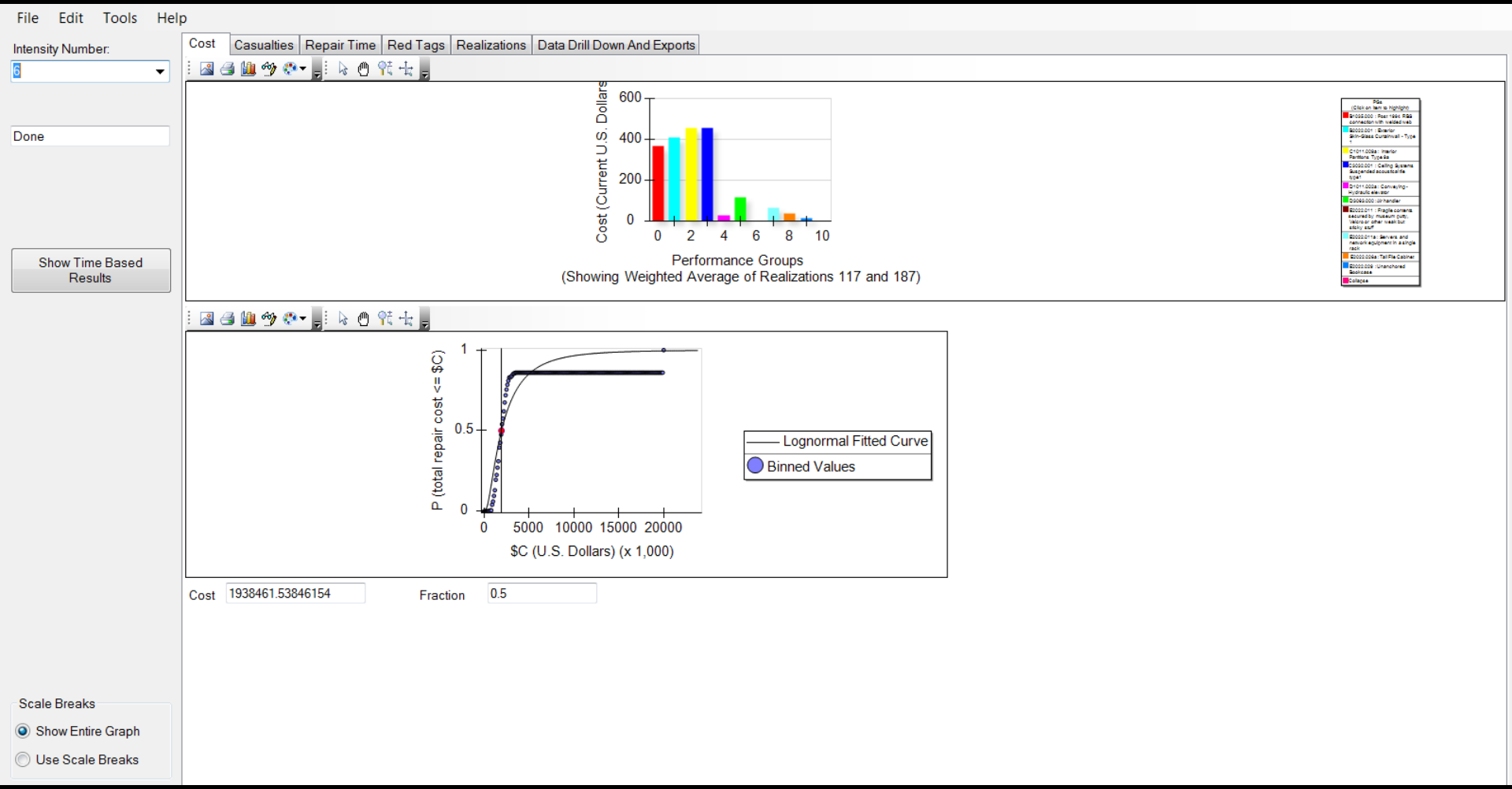
Computing Building Performance



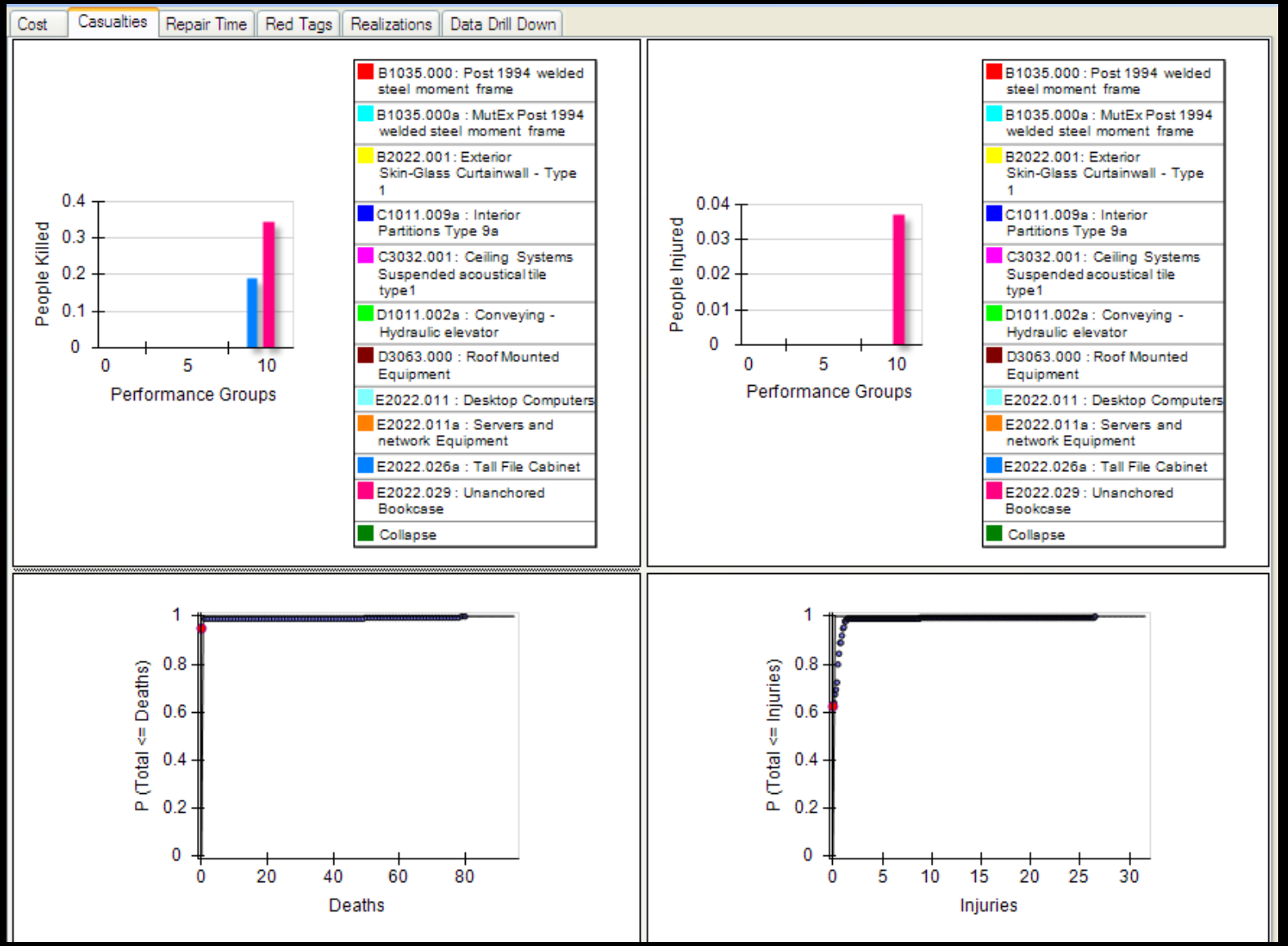
Performance Assessment Calculation Tool



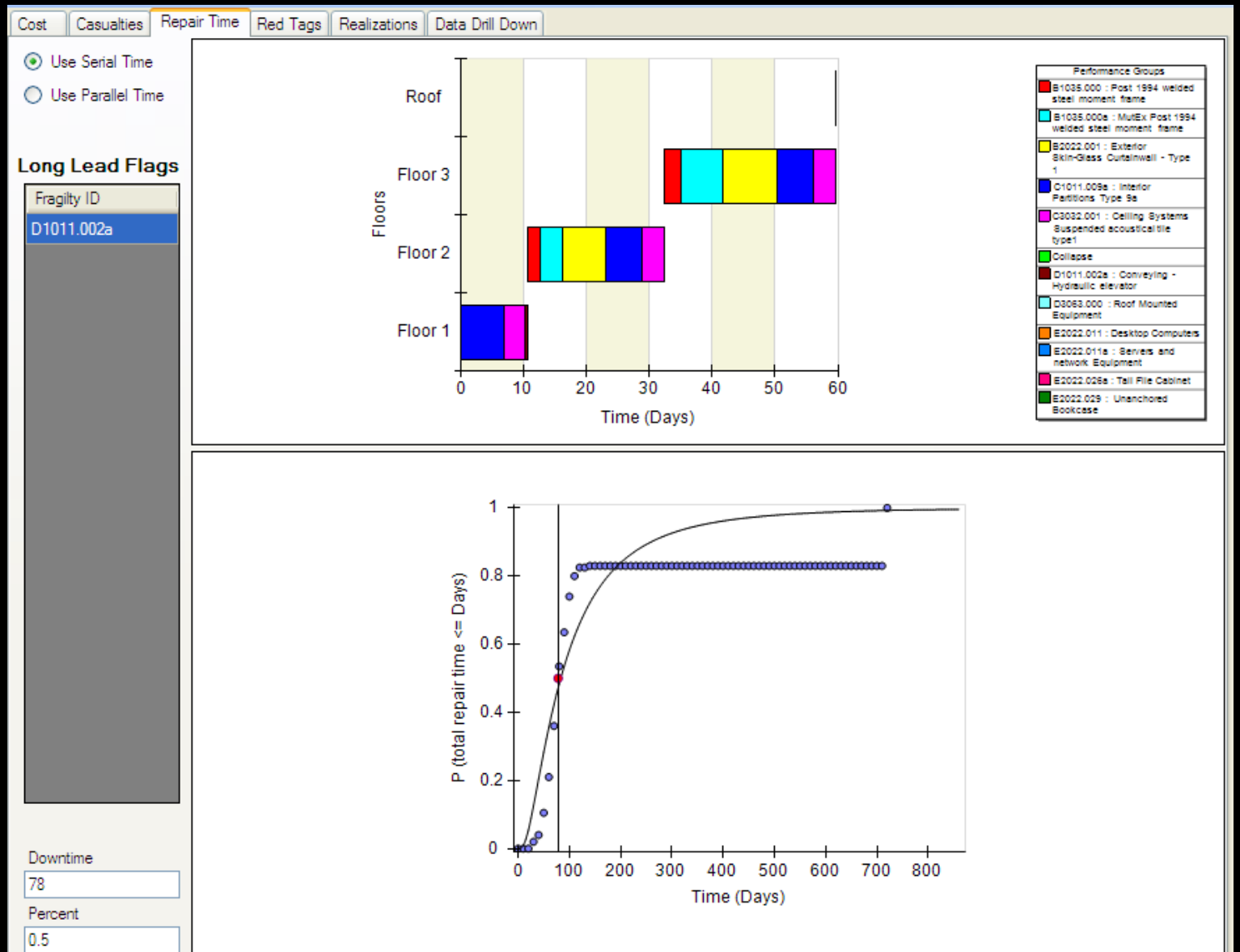
Repair Cost


File
Edit
Tools
Help
Intensity Number:
6
Done
Show Time Based Results
Cost
Casualties
Repair Time
Red Tags
Realizations
Data Drill Down And Exports
Cost (Current U.S. Dollars)
600
400
200
0
0 2 4 6 8 10
Performance Groups
(Showing Weighted Average of Realizations 117 and 187)
P (total repair cost <= $C)
1
0.5
0
0 5000 10000 15000 20000
$C (U.S. Dollars) (x 1,000)
Lognormal Fitted Curve
Binned Values
Cost
1938461.53846154
Fraction
0.5
Scale Breaks
Show Entire Graph
Use Scale Breaks

Casualties


Cost
Casualties
Repair Time
Red Tags
Realizations
Data Drill Down
People Killed
0.4
0.3
0.2
0.1
0
0
5
10
Performance Groups
B1035.000: Post 1994 welded steel moment frame
B1035.000a : MutEx Post 1994 welded steel moment frame
B2022.001: Exterior Skin-Glass Curtainwall - Type 1
C1011.009a : Interior Partitions Type 9a
C3032.001: Ceiling Systems Suspended acoustical tile type1
D1011.002a : Conveying - Hydraulic elevator
D3063.000 : Roof Mounted Equipment
E2022.011 : Desktop Computers
E2022.011a : Servers and network Equipment
E2022.026a : Tall File Cabinet
E2022.029 : Unanchored Bookcase
Collapse
People Injured
0.04
0.03
0.02
0.01
0
0
5
10
Performance Groups
B1035.000 : Post 1994 welded steel moment frame
B1035.000a : MutEx Post 1994 welded steel moment frame
B2022.001: Exterior Skin-Glass Curtainwall - Type 1
C1011.009a : Interior Partitions Type 9a
C3032.001: Ceiling Systems Suspended acoustical tile type1
D1011.002a : Conveying - Hydraulic elevator
D3063.000 : Roof Mounted Equipment
E2022.011 : Desktop Computers
E2022.011a : Servers and network Equipment
E2022.026a : Tall File Cabinet
E2022.029 : Unanchored Bookcase
Collapse
P (Total <= Deaths)
1
0.8
0.6
0.4
0.2
0
0
20
40
60
80
Deaths
P (Total <= Injuries)
1
0.8
0.6
0.4
0.2
0
0
5
10
15
20
25
30
Injuries

Repair Time


Cost
Casualties
Repair Time
Red Tags
Realizations
Data Drill Down
Use Serial Time
Use Parallel Time
Long Lead Flags
Fragilty ID
D1011.002a
Downtime
78
Percent
0.5
Roof
Floor 3
Floor 2
Floor 1
Floors
0
10
20
30
40
50
60
Time (Days)
Performance Groups
B1035.000 : Post 1994 welded steel moment frame
B1035.000a : MultEx Post 1994 welded steel moment frame
B2022.001 : Exterior Skin-Glass Curtainwall - Type 1
C1011.009a : Interior Partitions Type 9a
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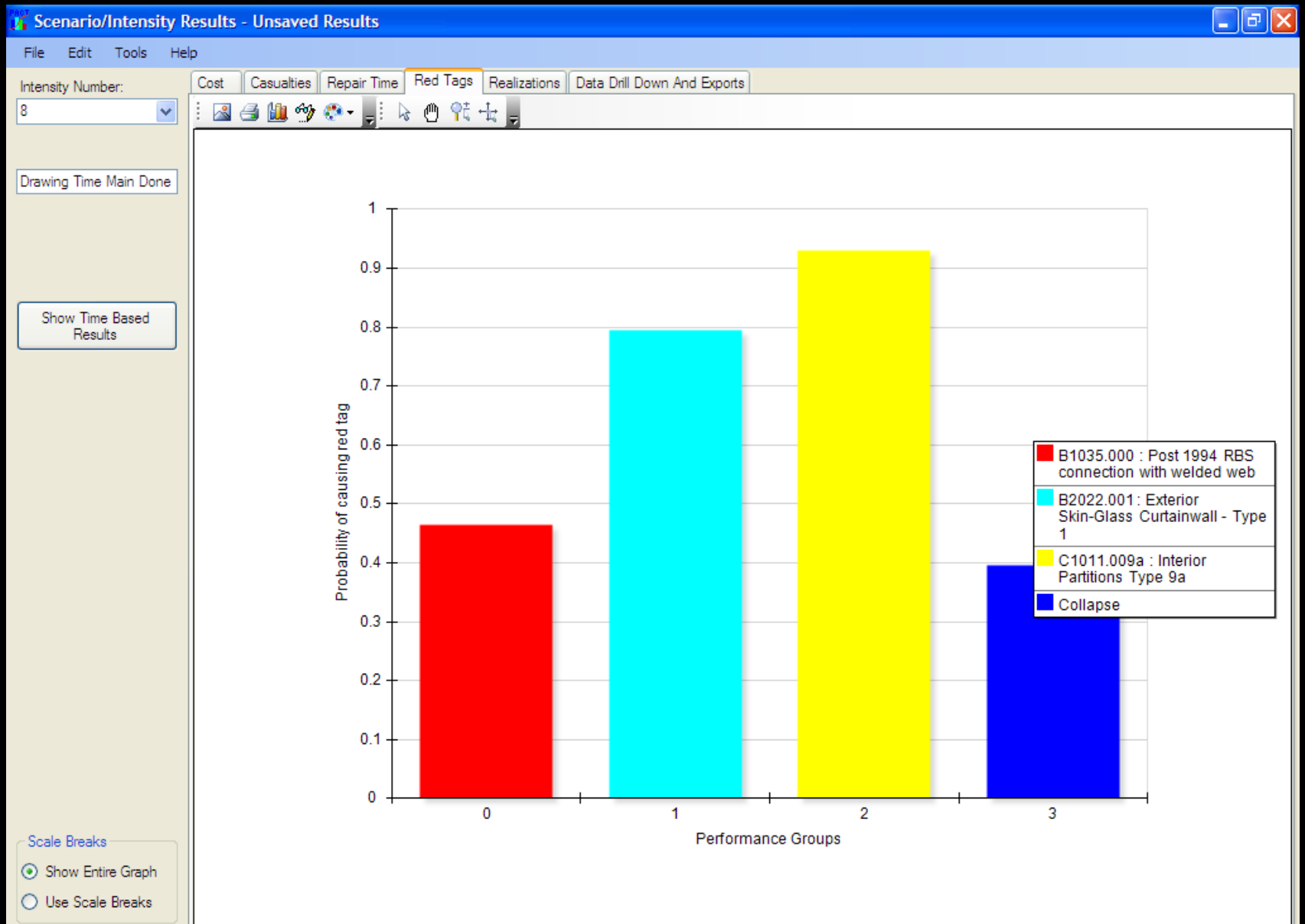
Collapse
D1011.002a : Conveying - Hydraulic elevator
D3063.000 : Roof Mounted Equipment
E2022.011 : Desktop Computers
E2022.011a : Servers and network Equipment
E2022.026a : Tall File Cabinet
E2022.029 : Unanchored Bookcase
P (total repair time <= Days)
1
0.8
0.6
0.4
0.2
0
0
100
200
300
400
500
600
700
800
Time (Days)

Unsafe Placards



On-going Development

- Continued refinement in the process
- Assessment of Code-designed buildings
  - What are we achieving?
- Guidance for providing better performance
- Primer for Structural Engineers
- Information to provide to Owners, Developers and Architects

Questions?